Ku-Band Traveling Wave Slot Array Using Simple Scanning Control

Nicholas K. Host, Chi-Chih Chen, and John L. Volakis
Ohio State University - ElectroScience Laboratory
Columbus, OH, USA

Félix A. Miranda
NASA John Glenn Research Center
Cleveland, OH, USA

***Abstract*—This paper introduces a feeding concept aimed at simplifying the backend (phase shifters) of traditional phased arrays. As an alternative to traditional phased arrays, we employ a traveling wave array (TWA) using a single feedline whose propagation constant is controlled via a single, small mechanical movement without a need for phase shifters to enable scanning. Specifically, a dielectric plunger is positioned within a parallel plate waveguide (PPW) transmission line (TL) that feeds the TWA. By adjusting the position of the dielectric plunger within the PPW feeding the TWA, beam steering is achieved.**

A 20 element array is designed at 13GHz shown to give stable realized gain across the angular range of $-25^\circ \leq \theta \leq 25^\circ$. A proof of concept array is fabricated and measured to demonstrate and validate the concept's operation.

I. INTRODUCTION

Phased arrays have garnered much interest for satellite applications [1] due to their conformality, unfettered beam steering, and other advantages as compared with traditional refectors. However, phased array properties come at the expense of cost and complexity. For example, current monolithic microwave integrated circuit (MMIC) phase shifters account for approximately 40% of a phased array cost [2]. Traveling wave arrays (TWAs) drastically reduce this cost by avoiding individual phase shifters at each element.

As an alternative to phased arrays, TWAs control the feedline propagation constant, k_{eff}, in a series-fed topology to enable scanning. This is often done via a small frequency change [3]. However, this approach may lead to limited scan ranges ($\pm 6^\circ$ for a 10% bandwidth). TWAs have also been designed using lumped elements [4] and ferrites [5] to control their feed's propagation constant, but both of these approaches are prone to enhance RF losses.

In this paper, we introduce a new TWA concept that avoids the aforementioned issues by instead positioning a dielectric plunger within the feedline of the TWA. Figure 1 depicts the proposed TWA configuration. This TWA employs a parallel plate waveguide (PPW) feed supporting a propagating wave that excites the slot antenna elements placed to the right of the PPW. The propagation constant within the PPW is controlled by adjusting the position of a dielectric plunger as depicted in Figure 2. This motion changes the feedline's air to dielectric ratio to enable scanning. This configuration has several advantages: 1) low cost, 2) low complexity, 3) large scan ranges (compared to frequency scanned arrays).

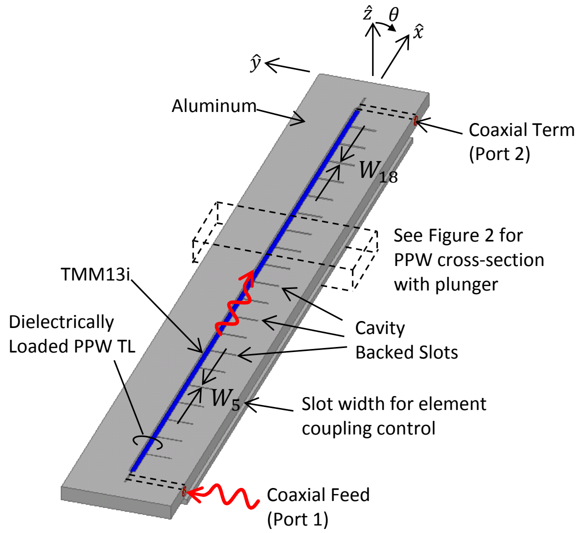

Fig. 1. Dielectric loaded parallel plate waveguide (PPW) array made mostly of metal for ease of fabrication where a rectangular dielectric plunger will be positioned within the PPW feedline to control the phase delivered to each slot element (and thus scan angle).

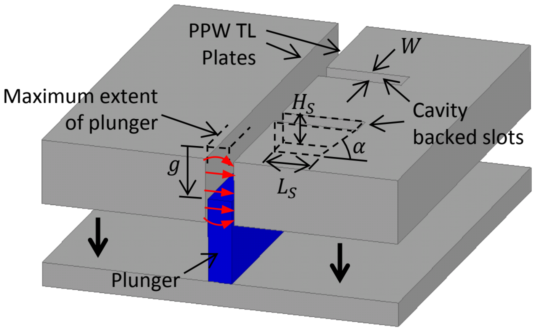

Fig. 2. Dielectric plunger to adjust the effective dielectric constant of the parallel plate controlling the phase delivered to each element.

II. ARRAY DESIGN

The key parameters of the dielectrically loaded PPW are depicted in Figure 3. The dielectric material choice plunger the plunger is important to the design. Here, we choose Roger's TMM13i ($\epsilon_r = 12.85$, $\tan\delta = 0.0019$) for the plunger because of its low loss and high permittivity (leading to large scan ranges). To allow movement of the plunger, its air gap to the PPW wall, C, was made $10mils$. Also, we set $H_1 = 30mils$ and $H_3 = 50mils$ for maximum scan range. Further, the thickness of the plunger, S_P, and substructure height, H_2, were chosen to be $100mils$ and $270mils$, respectively. With these dimensions, a scanning range of $-25° \leq \theta \leq 25°$ was achieved. The scan angle can be found from

$$\theta = \sin^{-1}\left(\frac{k_{eff}}{k_0} + \frac{n\lambda_0}{d}\right) \tag{1}$$

where, $k_0 =$ free space propagation constant, $k_{eff} =$ effective propagation constant within the PPW, $\lambda_0 =$ free space wavelength, $d =$ antenna element spacing, and $n = -1, -2, -3....$

To enable a good radiation pattern, the power delivered to each array element needs to be carefully controlled. To do so, the array element slot widths, W, along the TWA were adjusted based on a Kaiser array weighting [6]. Subsequently, an iterative design process was followed to achieve a stable realized gain at 13GHz across $-25° \leq \theta \leq 25°$.

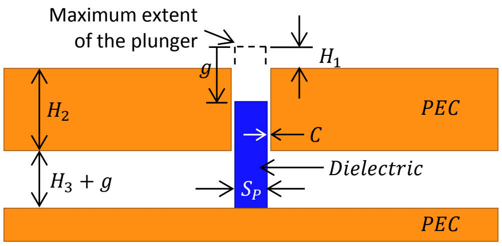

Fig. 3. Key parameters of the parallel plate waveguide (PPW) feeding the TWA.

III. PROTOTYPE MEASUREMENTS

We proceeded to validate the TWA design and demonstrate its scanning performance/array gain using a 20 element array. However, after consulting commercial fabrication shops, it was necessary to make some parameter adjustments to reduce fabrication complexity. Table I gives the changes between the optimal design values and the fabricated prototype dimensions.

TABLE I
PARAMETER VALUES FOR THE ARRAY DESIGN AND PROTOTYPE.

Parameter	**Design Value**	**Prototype Value**
Dielectric	TMM13i	TMM13i
C	10mils	6.5mils
S_P	100mils	100mils
H_1	30mils	-70mils
H_2	270mils	270mils
H_3	50mils	50mils
H_S	230mils	230mils
α	45°	45°
d	$0.65\lambda_0$	$0.54\lambda_0$

The prototype is shown in Figure 4. Corresponding measured realized gain patterns for different g values (plunger locations) are given in Figure 5. Here, we observe that the measured patterns are 1-2dB lower than simulated ones due to feed mismatches, but otherwise in agreement.

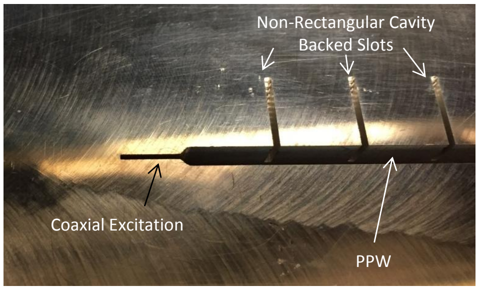

Fig. 4. Fabricated array prototype with showing the PPW at the center with the cavity-backed radiating slots above it (see Table I for dimensions).

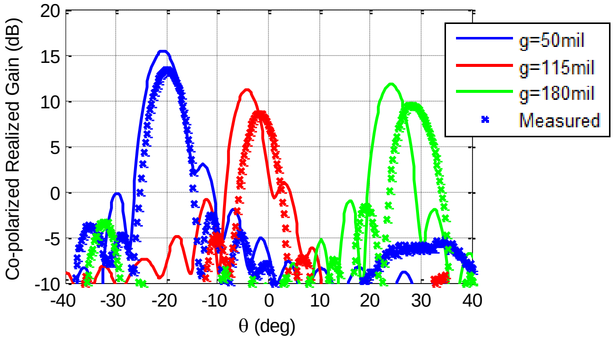

Fig. 5. Simulated (solid) and measured (x) co-polarized realized gain patterns of the prototype whose parameters are defined in Table I and its construction is depicted in Figure 4. Note that the measured patterns are 1-2dB below simulated, but otherwise are in good agreement.

IV. CONCLUSION

A new traveling wave array (TWA) concept was presented that has the following features: 1) simple and low cost construction. 2) Single feed to excite the array elements. The feeding was a simple metallic parallel plate waveguide (PPW) with the array elements being cavity-backed slots that feed off the PPW. 3) Single movement of a simple dielectric plunger within the PPW to control the effective propagation constant and therefore scanning. 4) Our 20 element array design achieved a stable realized gain ($\approx$16dB) across $-25° \leq \theta \leq 25°$. A version of the array was measured, validating the concept.

REFERENCES

[1] M. Anjum *et al.*, "Design and analyze the airborne satellite communication using phased array antenna for reliable communications," in *5th IET Int. Conf. on Wireless, Mobile and Multimedia Networks*, Nov 2013, pp. 164–167.

[2] R. York *et al.*, "Thin-film phase shifters for low-cost phased arrays," in *Workshop on Affordability and Cost Reduction for Radar Systems*, Huntsville, Alabama, April 2000, p. 10.

[3] F. Xu *et al.*, "Periodic leaky-wave antenna for millimeter wave applications based on substrate integrated waveguide," *IEEE Trans. on Antenna and Propag.*, vol. 58, no. 2, 2010.

[4] M. Archbold *et al.*, "Beam steering of a half-width microstrip leaky-wave antenna using edge loading," *IEEE Antennas and Wireless Propagation Letters*, vol. 9, pp. 203–206, 2010.

[5] N. Apaydin *et al.*, "Nonreciprocal leaky-wave antenna based on coupled microstrip lines on a non-uniformly biased ferrite substrate," *IEEE Trans. on Antenna and Propag.*, vol. 61, no. 7, pp. 3458–3465, 2013.

[6] F. Harris, "On the use of windows for harmonic analysis with the discrete fourier transform," *Proc. IEEE*, vol. 66, no. 1, pp. 51–83, Jan 1978.